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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING FEBRUARY, 1932

By HERBERT H. KIMBALL, in charge Solar Radiation Investigations

For a description of instruments employed and their exposures, the reader is referred to the January, 1932 REVIEW, page 26.

Table 1 shows that solar radiation intensities averaged above the normal intensity for February at Washington, close to the February normal at Lincoln, and slightly below at Madison.

Table 2 shows an excess in the total solar radiation received on a horizontal surface at Chicago, New York, Fresno, Pittsburgh, Twin Falls, La Jolla, and Miami, and a deficiency at Washington, Madison, Lincoln, and Gainesville.

No skylight polarization measurements were obtained during the month. At Madison the presence of snow in the vicinity of the station made such readings of doubtful value, and at Washington the polarimeter was undergoing repairs.

TABLE 1.—*Solar radiation intensities during February, 1932*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass									Local mean solar time
		A. M.					P. M.				
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Feb. 1	1.24	0.86	0.97	1.14	1.28	1.44	1.30				1.32
Feb. 5	2.36				1.22		1.24				2.26
Feb. 8	7.57						1.25	1.09	0.92	0.75	6.50
Feb. 13	4.42	0.92	1.03	1.09							2.26
Feb. 16	2.16		0.85	1.00	1.18						2.39
Feb. 18	1.96	0.82	0.92	1.13	1.33	1.46	1.17				1.96
Feb. 20	2.06	0.97	1.11	1.24	1.41	1.55					1.96
Feb. 23	1.68						1.16	0.95			1.52
Feb. 29	4.37	0.51	0.62	0.78							4.75
Means		0.82	0.92	1.06	1.28	1.48	1.22	(1.02)	(0.92)	(0.75)	
Departures		+0.10	+0.10	+0.07	+0.10	−0.01	+0.03	+0.04	+0.06	−0.01	

[1] Extrapolated.

TABLE 1.—*Solar radiation intensities during February, 1932*—Continued

[Gram-calories per minute per square centimeter of normal surface]

Madison, Wis.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass									Local mean solar time
		A. M.					P. M.				
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Feb. 3	1.37	0.73	0.93	1.18	1.34		1.34	1.22			1.52
Feb. 4	1.88						1.37	1.15			1.78
Feb. 5	1.96			1.05	1.23			1.16			2.49
Feb. 8	2.87	0.95	1.12	1.26	1.45						1.24
Feb. 12	2.26	0.82	1.00	1.17	1.40						1.88
Feb. 13	1.32	0.93	1.05	1.21	1.41						1.24
Feb. 18	1.52				1.25						2.62
Feb. 20	2.06		0.98								2.16
Feb. 23	1.12		0.82		1.20						1.02
Feb. 26	4.75			1.14							5.56
Feb. 27	4.95				1.19						5.16
Feb. 29	3.45			1.24	1.49						2.63
Means		0.86	0.98	1.18	1.33		(1.36)	1.18			
Departures		−0.08	−0.10	−0.02	−0.03		±0.00	+0.01			

Lincoln, Nebr.

Date	8 a.m.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	Noon
Feb. 3	0.96		0.78	0.98							0.86
Feb. 4	0.81		1.01	1.20	1.21						0.96
Feb. 5	2.36			1.15	1.33						3.45
Feb. 6	3.63	0.81	0.89	1.03	1.28						3.45
Feb. 11	4.17		1.05	1.22	1.36		1.39	1.22	1.05	0.85	3.99
Feb. 12	2.87							1.31	1.18	1.06	2.87
Feb. 17	1.52	1.03	1.18	1.31	1.45		1.45	1.09	0.84	0.81	1.68
Feb. 19	2.16		1.04	1.25	1.41		1.41	1.08	0.93		2.36
Feb. 22	1.96	0.98	1.01	1.13	1.38		1.23				2.87
Feb. 25	4.95	0.84	0.91	1.11	1.34						5.36
Means		0.95	0.96	1.15	1.34		1.37	1.18	1.00	0.91	
Departures		+0.01	−0.03	−0.03	−0.03		+0.02	+0.02	−0.06	−0.01	

[1] Extrapolated.

TABLE 2.—*Average daily totals of solar radiation (direct + diffuse) received on a horizontal surface*

[Gram-calories per square centimeter]

Week, beginning	Washington	Madison	Lincoln	Chicago	New York	Fresno	Pittsburgh	Fairbanks	Twin Falls	La Jolla	Gainesville	Miami	New Orleans
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Jan. 29	146	175	244	107	95	186	118	20	191	318	-----	375	216
Feb. 5	202	156	270	121	169	295	140	55	184	250	[1] 256	425	----
12	228	221	206	187	232	388	219	51	311	233	[2] 239	440	----
19	270	285	308	254	267	418	168	102	358	364	205	394	171
	Departures from weekly normals												
Jan. 29	−51	−14	+12	−9	−43	−44	−3	-----	+4	+62	-----	+19	----
Feb. 5	±0	−50	+8	−4	+28	+19	−5	-----	−36	+1	−36	+57	----
12	+2	−7	−70	+45	+72	+62	+54	-----	+48	−41	−52	+70	----
19	+14	+33	+7	+86	+75	+62	+6	-----	+80	+40	−119	+36	----
	Accumulated departures on February 25												
	−721	−1,785	−917	+651	+448	+1,533	+91	-----	−49	+1,456	-----	+2,527	----

[1] 4-day mean. [2] 6-day mean.

ATMOSPHERIC DEPLETION OF SOLAR RADIATION

The primary object of the measurements of screened solar radiation, I_y and I_r given in Table 3, is to determine the value of the coefficient of atmospheric turbidity, β, or the atmospheric depletion of solar radiation by scattering, aside from the scattering by the gas molecules of dry air.

According to Fowle and others, the depletion of solar radiation of a given wave length, λ, through atmospheric scattering, may be expressed by the equation

$$I_\lambda = I_{0\lambda}\, e^{-(a_1+a_2)\, m} \tag{1}$$

Here, I_λ = the measured intensity of solar radiation of wave length λ;

$I_{0\lambda}$ = the intensity of radiation of the same wave length before it entered the atmosphere;

e = the base of the Naperian system of logarithms;

a_1 = the coefficient of extinction of solar radiation of wave length λ, through scattering by atmospheric gas molecules.

a_2 = the coefficient of extinction through scattering by other constituents of the atmosphere, principally dust, and which also may be represented by $\frac{\beta}{\lambda^a}$. For ordinary atmospheric dust $a = 1.3$, as contrasted with 4.0 for molecular scattering. Therefore, while the scattering for dust is a function of the wave length, λ, the value of the coefficient, β, is independent of wave length.

m = the air mass, or the length of the path of the solar rays through the atmosphere in terms of its length when the sun is in the zenith, or approximately the secant of the sun's zenith distance.

In Smithsonian Meteorological Tables, Fifth Revised Edition, 1931, Table 111 gives values of $I_{0\lambda}e^{-a_1}$, or $a_{a\lambda}$, the atmospheric transmission coefficient for pure dry air at a pressure of 760 millimeters, for wave lengths between 0.3504 μ and 2.442 μ. There are also given values of the relative intensity of solar radiation before it entered the atmosphere, $e_{o\lambda}$, over the same range of wave lengths, and likewise its intensity after passing through pure dry air at 760 millimeters pressure. At the foot of each column of Table 111 will be found the relative intensity of energy in selected sections of the spectrum, and it may be determined for any section desired.

From this table the curves of Figure 1, page lxxxiv were constructed, except that the latter do not include the absorption by the permanent gases of the atmosphere, which is given near the foot of columns 5 to 10, Table 111.

It therefore becomes possible to determine from the data of Table 111 the solar radiation intensity between any desired spectrum limits after depletion by pure dry air, provided a constant value for the solar output of radiant energy is assumed. Apparently such an assumption is within the probable error of the screened measurements, since 1,007 solar constant determinations made at Mount Montezuma, Chile, between August 1, 1925, and July 31, 1931, give a standard deviation of ± 0.00856.

The red-glass filter obtained from the Potsdam Observatory transmits about 90 per cent of the radiation between wave lengths 0.625 and 2.850μ, or the section of the solar spectrum that includes all the important atmospheric absorption bands except those due to ozone. If, therefore, the intensity as measured is divided by the transmission coefficient for the filter and subtracted from the intensity for the entire spectrum as given by a pyrheliometric reading, the remainder will give the intensity in that part of the spectrum below 0.625μ, which is relatively free from atmospheric absorption bands. Then the difference between the measured intensity of radiation below 0.625μ and the intensity determined from Table 111 will give the depletion, in this part of the spectrum by dust, including what Fowle has designated wet dust, and some absorption by ozone. This latter must be a very small amount, since Fowle has estimated the entire absorption of solar radiation of wave length greater than 0.350μ by the permanent gases of the atmosphere to be only 0.012 gr. cal. per min. per sq. cm.[1], and by ozone, between wave lengths 0.450μ and 0.650μ to be between 0.002 and 0.010 gr. cal.[2]

The above steps may be expressed mathematically as follows:

$$I_m - \frac{1}{\gamma} I_r = \int_0^{0.625\mu} I_{o\lambda}\psi\,(m, \beta, \lambda)\, d\lambda. \tag{2}$$

This equation may be adapted to a screen of slightly different transmission coefficients and wave-length limits as follows:

$$bI_m - c\,\frac{1}{\gamma} I_r = \int_0^{0.625\mu} I_{o\lambda}\psi\,(m, \beta, \lambda)\, d\lambda. \tag{3}$$

Ångström integrated equation (2) for an upper wave-length limit of 0.600μ and for different values of β and m, and plotted these integrals as ordinates against m as abscissas. The integrals for different values of β fall on curves that meet at the point where the curve for $\beta = 0$ (no depletion from dust) cuts the ordinate for zero atmosphere. (Geografiska Annaler, Årg. xii, Heft 2, och 3, 1930, p. 142, fig. 5.)

To adapt readings, I_r, obtained with the red filters furnished by Potsdam to his diagram, Ångström[3] found that in equation (3)

$$b = 0.95 \text{ and } c = 1.09$$

I have applied these factors to measurements obtained at Washington with the results given in Table 3.

[1] Smithsonian Meteorological Tables, Fifth Revised Edition, 1931, p. lxxxiv and Table 111.

[2] Fowle, Frederick E. Atmospheric Ozone: Its relation to some solar and terrestrial phenomena. Smithsonian Misc. Coll. vol. 81, No. 11, p. 8.

[3] Geografiska Annaler. Årg. XII, Häft. 2 och 3, 1930. Footnote, p. 144.

TABLE 3.—*Solar radiation measurements, and determination of the atmospheric turbidity factor, β. Washington, D. C., February, 1932*

[Values in italics have been interpolated]

Date and solar hour angle	Solar altitude, h.	Air mass, m.	I_m	I_y	I_r	β	Blueness of sky (scale, 0-14)	Atmospheric dust particles per cubic centimeter	Notes
Feb. 1	° ′								
			gr. cal.	gr. cal.	gr. cal.				
3:46 a.	13-28	4.23	0.921	0.739	*0.649*	0.085		905	
3:32 a.	16-42	3.44	1.075	*.788*	0.681	.060			
3:04 a.	19-15	3.02	1.127	.834	*.691*	.060			
2:30 a.	23-45	2.48	1.207	.894	*.721*	.060			
2:21 a.	24-50	2.37	1.181	*.901*	.724	.080			
1:42 a.	28-53	2.06	1.216	*.911*	.733	.088	5		
0:07 a.	33-46	1.80	1.308	.910	*.750*	.070			
0:06 p.	33-47	1.79	1.331	*.910*	.752	.065			Stopped by clouds.
Feb. 5									
1:39 p.	30-18	1.98	1.238	*.911*	.700	.065		611	
1:46 p.	29-42	2.02	1.246	.908	*.702*	.060	5		Clouds, a. m.
Feb. 8									
2:19 p.	26-53	2.21	1.222	.895	*.720*	.070	6	1,140	Clouds, a. m., now disappearing.
2:26 p.	26-06	2.27	1.207	*.891*	.724	.072			
3:06 p.	20-38	2.82	1.136	.848	*.681*	.058			
3:13 p.	19-35	2.97	1.084	*.824*	.671	.065			
3:40 p.	15-24	3.73	.994	.735	*.624*	.075			
Feb. 13									
3:17 a.	20-23	2.85	1.099	*.839*	.645	.055		410	
2:43 a.	25-23	2.32	1.168	*.859*	.678	.065			
2:34 a.	26-34	2.23	1.203	.870	*.682*	.058			
1:18 a.	34-30	1.80	1.282	*.918*	.725	.070			
1:10 a.	35-00	1.76	1.288	.920	*.727*	.070			Clouds, p. m.
Feb. 16									
3:30 a.	19-22	3.01	.986	*.736*	.611	.075		1,132	Much smoke over city.
2:48 a.	25-24	2.32	1.115	.837	*.672*	.070			
2:41 a.	26-18	2.24	1.143	*.840*	.685	.082			
2:02 a.	31-08	1.94	1.157	.850	*.700*	.110	4		
1:56 a.	31-56	1.88	1.164	*.853*	.697	.115			Clouds, p. m.
Feb. 18									
3:37 a.	18-23	3.16	1.111	.827	*.706*	.065		284	
3:02 a.	23-48	2.48	1.165	*.875*	.716	.076			
2:55 a.	24-53	2.38	1.189	.888	*.725*	.074			
2:35 a.	27-41	2.18	1.282	*.930*	.754	.062			
2:26 a.	29-19	2.08	1.295	.946	*.768*	.065			
2:19 a.	29-46	2.06	1.314	.960	*.778*	.064	5		
0:50 a.	37-52	1.63	1.372	*1.003*	.778	.070			
0:44 a.	38-16	1.60	1.384	1.004	*.780*	.068			
0:52 p.	37-52	1.62	1.324	*.922*	.752	.080			
1:02 p.	37-14	1.64	1.278	.924	*.758*	.105			
1:58 p.	32-18	1.88	1.170	.875	*.702*	.105			
2:04 p.	31-38	1.90	1.186	*.852*	.690	.090			Stopped by clouds.
Feb. 20									
3:51 a.	16-33	3.46	1.162	*.901*	.727	.045		746	
3:46 a.	17-32	3.30	1.203	*.916*	.740	.045			
3:25 a.	19-16	3.01	1.239	.935	*.760*	.042			
3:01 a.	24-25	2.38	1.328	.984	*.777*	.042			
2:54 a.	25-36	2.31	1.350	.991	*.783*	.040			
2:45 a.	26-54	2.20	1.367	*1.000*	.791	.040			
2:36 a.	28-13	2.12	1.381	1.010	*.802*	.045			
2:29 a.	29-05	2.05	1.382	*1.014*	.815	.052			
2:24 a.	29-45	2.01	1.398	*1.014*	.815	.050	6		
0:46 a.	38-46	1.60	1.453	1.009	*.798*	.045			
0:36 a.	39-13	1.58	1.448	*.999*	.794	.045			
Feb. 23									
1:20 a.	37-36	1.64	1.218	.891	*.716*	.115		561	Clouds, a. m.
1:14 a.	38-04	1.62	1.222	*.891*	.716	.112			
3:06 p.	24-44	2.38	1.093	.792	*.634*	.075			
3:11 p.	23-53	2.46	1.060	*.786*	.634	.092			
3:31 p.	20-28	2.85	.976	*.708*	.598	.082			Stopped by clouds.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, Perkins, and Mount Wilson Observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time		Heliographic			Area		Total area for each day
			Diff. long.	Longitude	Latitude	Spot	Group	
1932	H	m	°	°	°			
Feb. 1 (Naval Observatory)	11	4	+3.0	172.4	+13.0	77	------	------
			+70.0	239.4	−13.0	62	------	139
Feb. 3 (Naval Observatory)	13	38	+31.0	172.6	+13.5	62	------	62
Feb. 4 (Yerkes Observatory)	12	19	+43.5	172.7	+12.8	88	------	88
Feb. 5 (Naval Observatory)	10	28	+56.0	173.0	+13.0	46	------	46
Feb. 6 (Yerkes Observatory)	15	10	+70.7	171.9	+12.9	100	------	100
Feb. 7 (Naval Observatory)	11	35		No spots		------	------	------
Feb. 8 (Naval Observatory)	14	46		No spots		------	------	------
Feb. 9 (Naval Observatory)	11	34		No spots		------	------	------
Feb. 10 (Naval Observatory)	14	44	−1.0	47.8	−5.0	------	25	25
Feb. 11 (Naval Observatory)	11	3	+12.0	49.7	−6.0	------	15	15
Feb. 12 (Yerkes Observatory)	------	------		No spots		------	------	------
Feb. 13 (Naval Observatory)	11	0		No spots		------	------	------
Feb. 14 (Yerkes Observatory)	------	------		No spots		------	------	------
Feb. 15 (Naval Observatory)	11	5		No spots		------	------	------
Feb. 16 (Naval Observatory)	10	42		No spots		------	------	------
Feb. 17 (Yerkes Observatory)	------	------		No spots		------	------	------
Feb. 18 (Naval Observatory)	11	47		No spots		------	------	------
Feb. 19 (Naval Observatory)	14	31		No spots		------	------	------
Feb. 20 (Naval Observatory)	10	32		No spots		------	------	------
Feb. 21 (Yerkes Observatory)	------	------		No spots		------	------	------
Feb. 22 (Naval Observatory)	12	51		No spots		------	------	------
Feb. 23 (Naval Observatory)	10	38	−48.0	191.9	+5.0	------	31	------
			−6.0	233.9	−12.0	------	31	------
			−1.0	238.9	−15.0	------	12	74
Feb. 24 (Mount Wilson)	10	50	−33.0	193.6	+5.0	------	45	------
			+7.0	233.6	−12.0	------	17	------
			+14.0	240.6	−15.0	4	------	66
Feb. 25 (Naval Observatory)	10	49	−18.0	195.5	+5.0	------	278	278
Feb. 26 (Naval Observatory)	10	46	−4.5	195.8	+5.0	------	432	432
Feb. 27 (Naval Observatory)	11	5	+10.0	197.0	+5.0	------	463	463
Feb. 28 (Mount Wilson)	12	30	−65.0	108.0	+13.0	------	248	------
			+24.0	197.0	+4.0	------	351	599
Feb. 29 (Naval Observatory)	10	47	−52.0	108.8	+12.5	------	278	------
			+37.0	197.8	+5.5	------	309	587
Mean daily area for February	------	------	------	------	------	------	------	106

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR FEBRUARY, 1932 [1]

[Data furnished through the courtesy of Prof. W. Brunner, University of Zurich, Switzerland]

February, 1932	Relative numbers	February, 1932	Relative numbers	February, 1932	Relative numbers
1	19	11	9	21	0
2	16	12	7	22	0
3	17	13	0	23	Ec 18
4	8	14	0	24	23
5	8	15	0	25	26
6	8	16	0	26	26
7	7	17	0	27	d 39
8	7	18	0	28	31
9	--------	19	0	29	29
10	9	20	0		

Mean: 28 days=11.0.

[1] Dependent alone on observations at Zurich and its station at Arosa.

a = Passage of an average-sized group through the central meridian.
b = Passage of a large group or spot through the central meridian.
c = New formation of a center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central zone.
d = Entrance of a large or average-sized center of activity on the east limb.